Exploring Gesture Sonification to Support Reflective Craft Practice

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ABSTRACT
Much of the knowing employed in skilled craft practice is difficult to communicate solely through written or verbal description. Consequently, the reflection and development of a craft practice in this manner may miss important nuances of practitioners' skills and experiences. We created digital technologies to sonify (using audio to perceptualize data) a group of craft practitioners' gestures to explore how we can aid their reflection in and on their craft, and consequently develop it. Over a number of workshops, the design of these sonifications were iterated based on how the practitioners responded to them. We found that direct sonification of gesture (sounds generated directly from motion sensor data) helped practitioners understand and reflect upon their own and each other's practice, encouraged discussion and enabled modification of craft technique.

Author Keywords
Craft Skills; Sonification; Reflective Practice

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI)

INTRODUCTION
Craft skill is developed through reflection in and on practice [19] often through practice alongside a more experienced practitioner [24]. In this study we explore how digital systems can support such reflection. By craft skill we refer to the elusive knowing through which practitioners perform and develop their craft. Parts of this knowing can be articulated by the craft practitioner through speech and demonstration [23]. However, other parts are less easily communicated (e.g. how much pressure to apply when working a material) and are frequently learned by *doing*. Such nuance may be reflected in the movements employed in skilled practice, so in this study we chose to investigate how the translation of gesture into sound can support practitioners' reflection upon and consequent development of their craft.

We followed a research through design [5][25] approach in which we investigated how transforming practitioners' gestures into sound could facilitate understanding of their craft practice through iteratively designing a digital sonification system. By working with a group of craft practitioners, we designed different forms of sonifications to help practitioners reflect, discuss and in some cases modify their craft techniques over the course of three workshops. Background research, observations made during the workshops and collective critical reflection after each workshop informed our sonification design for subsequent workshops. Our response to the insights that arose from the workshops was to design and develop a system that can replay captured data, along with captured video of the practitioners' gestures while designing sonifications live, allowing us to rapidly prototype the sonifications which we then presented to the practitioners in the following workshop.

We describe our design process for creating a data capture and sonification system and how we explored these sonifications' use throughout the workshops. We present findings on how sonification allowed craft practitioners to reflect on their practice, and discuss the implications for designing digital systems to support reflection upon and development of craft practice. In doing so, we highlight to the HCI community the sonic representation of craft skills as an opportunity for further research.

BACKGROUND

Craft Skills
The practical understanding of craft practice has primarily been investigated from two approaches: firstly through the critical analysis of tools and artefacts that result from the technical process of craft practice; and secondly through reflective descriptions of the process of making by the

CHI 2015, April 18–23, 2015, Seoul, Republic of Korea.

ACM 978-1-4503-3145-6/15/04…$15.00.
http://dx.doi.org/10.1145/2702123.2702497

practitioners themselves and observers. Although these approaches bring us closer to understanding craft practice, they have recently been found to be incomplete.

Barad [2] discusses the challenges with regard to this material semiotic approach to "things", suggesting that accounts developed by deconstructing artefacts to understand the processes that generate them will be unable to construct a cohesive account of the process. For Barad, any change to the context of an artefact alters the meaning that any future actors and agents might construct, suggesting that any extended interpretations derived from artefacts become contextually sensitive as well. With regard to descriptive accounts by practitioners, Perry & Krippendorff [14] suggest that a use of protocol analysis in design activity may be challenging due to the inability for researchers to come to a consensus when categorizing these descriptions. Wood [23][24] discusses the challenges faced by practitioners in communicating their craft knowledge, for example observing how a bowl turner describes his practice in one way (only using one tool) but her video recording demonstrates that his actions are counter to his description (he changes tools during the process) [23, p.35].

Polanyi [15] introduced tacit knowing (which has subsequently been used to characterize craft skill, e.g. [23][24]), describing it as "we can know more than we can tell" [15, p.4], i.e. some aspects of craft practice become internalized and cannot be articulated by the practitioner. Ingold [10] offers an alternative view by focusing on the 'telling' rather than the 'knowing' and observing that we can tell what we know *"through practice and experience"* [10, p.109], avoiding the problem of specification and articulation Polanyi requires from practitioners. Therefore, through exploring the performance of a craft rather than the verbal articulation of a craft, we may support the understanding of craft skills in additional ways.

The concept of performativity introduced by Butler [3] describes gestures, speech and other performative actions as constructors of identity. From this view gestures are an expression of a craft. Although gesture cannot capture a craft in its entirety (e.g. given the tactile feedback that a craft involves), exploring the craft practitioners' performative gestures during making, rather than analyzing what is made and descriptions of making, could provide some insight into those practices. If performative actions are, to some extent, an expression of a craft, then the use of a body-worn sensor for recording gestures is a possible means for helping practitioners develop their craft. This poses the question: how do we represent this gestural data in a way that is useful to practitioners?

Representing Data

The ability to represent gestural data so that it is meaningful and useful to the target audience is non-trivial. Each set of data is contextual and requires careful thought to be able to be represented effectively. The aesthetic form and function are both important to the effectiveness of a data representation.

Data Visualization

The most common form of representation is visualization. Data visualization has not only become a substantial research area for statisticians and designers but it has also entered the cultural consciousness, and being used by popular magazines and websites. Data visualization refers to the ability to use space, color and other visual properties to help disseminate information from an otherwise complex dataset. Gestural data is seldom visualized due to the fact that it is inherently three-dimensional but a number of art projects have made use of visualization to let users explore the data [7]. For our project, the use of data visualization is not ideal as we do not want to divide the craft practitioners' attention between their craft and a screen when relying on hand-eye coordination [21].

Data Sonification

Using a sense that is less central to a making process would be less disruptive: therefore we are exploring data sonification. Sonification refers to representing data through auditory means. Rather than using visual properties such as space and color to convey the data in a meaningful way, we use amplitude, frequency and temporality. Sonification is defined by Hermann [9] as *"[T]he data-dependent generation of sound, if the transformation is systematic, objective and reproducible, so that it can be used as scientific method."*

Sonification has been explored in many areas where data visualization would not be appropriate – such as when a user's actions would be hindered if their visual attention is divided between the task at hand and a screen, the data is more meaningful when represented temporally or the user is visually impaired. For example, within the ICAD [11] community, there has been much research into using sonifications to aid sports athletes in training [6][17][18]. These projects translate the movement data of the athletes in different ways. Either the sound is generated by passing the data through a design system which is known as *sonification* [9] or directly generated from the movement data which is known as *audification* [8]. Sports activities are comparable to craft practice as both involve repeated movements in a temporal frame. Therefore, the concepts used for sports sonification are viable to explore in craft practices.

The aesthetic design of the sonifications will be significant to how they are perceived. Jensenius' concept of artificial action-sound relationships [12] describes how we design artificial sounds that react to actions (gestures) and discusses the need for practical action-sound design to "enhance the interaction between humans and technological devices".

RESEARCH THROUGH DESIGN

Due to the exploratory nature of this study, we had many decisions to make in terms of how to approach the problem space. We are exploring how sonifications can facilitate craft practitioners' understanding of their own and other's practice by exposing its performative aspects. As sonifications have not been used for craft practice previously, care was needed in approaching the problem. We did not want to restrict the enquiry by pre-defining too many elements of the sonification system, nor did we wish to leave the design of this system completely open and risk lack of progress. We therefore adopted a research through design approach [5][25], drawing on the design strengths of the researchers to design sonifications (and the system to generate them) in direct response to how craft practitioners used them, whilst also establishing an understanding of the effect of such sonifications on craft practice.

We decided to design a sonification system to be used in a series of workshops with a group of craft practitioners. Based on how the practitioners experienced the system, we would form design insights, iterate the design of the system and present the new system back to the participants for further exploration.

Our approach was further informed by the interdisciplinary skills within our research team. The team included an interaction designer, a design researcher with a focus on craft practice and a computer scientist. These different disciplines allowed us to be confident in following a fast-paced, iterative method.

Researchers took field notes, audio and video recordings of the workshops alongside audio and video data recorded by the sonification system, and collectively discussed activities and observations immediately after them. This critical reflection during the project both informed the design work and research enquiry. We include an account of the activities and thinking of our design, so that this research through design is available for others to critique [25]. The findings that we present were made during these post-workshop discussions and our critical reflection of the study as a whole.

Design Choices

The project imposed a practical constraint that we needed to prototype a working sonification system that could be iteratively used by practitioners and re-developed within the project timescale. Design choices were then made at the start of the study to ensure that this was possible.

To frame our initial enquiry we chose a relevant craft domain that was also readily accessible to the research team. This had implications for our choice of technology to capture the craft's performative actions, the group of participants with which we would work, and the system we would create, not only to process and play the sonifications back to the practitioner in real time but also to allow for analysis between workshops and to iterate its design.

Choice of Craft

Craft practice covers a wide range of different activities and processes; some crafts require large and complex machinery while others only require the practitioner's hands. We developed a taxonomy of different crafts according to the tools used and the prevalence of repeated gestures to inform our selection of craft domain (Table 1). We chose to focus on tool-based textile crafts due to the way these crafts are performed. Firstly, the use of the tool is very important and direct in practicing these crafts, allowing us to focus our attention on the gestural use of the tool. Secondly, artefacts are produced by performing a set of repeated gestures, allowing us to focus our sonification designs around these gestures.

Type of tool	Description	Example crafts
Hand	Using hands to affect material	Basket weaving, pottery, origami
Hand Tools	Tool as extension of hand to affect material	Crochet, wood turning, weaving
Machine Tools	Holding material and using machine to affect it	Sewing with machine, furniture making, metalworking
Digital Tools	Affecting material on digital device	Animation, 3D modelling

Table 1. Taxonomy of craft with respect to the tools used.

We decided to focus on two particular textile crafts: crochet and hooky matting. Crochet is a textile craft that has similarities to knitting although only one needle is used with a hook at its tip. The skill of crocheting is in working the hook in one hand while holding the wool in the other hand. In contrast, the craft of hooky matting is a traditional (local) rug making techniques using strips of old fabric. This craft requires the user to control a tool with one hand and the material with the other. We chose to also include the use of hooky matting because of its similarities to crochet, the idea being that this would allow us to explore how participants used the sonifications in a similar, yet foreign, craft.

Another reason for choosing to focus on crochet was that one of the researchers is also a crocheter and therefore had an understanding of the vocabulary and concepts used by the craft practitioners. This researcher also gave us access to a local community of practitioners to work with.

Choice of Technology

In response to the gestures performed in the selected craft practices, the technology we used to capture craft gestures must not hinder the practitioner in performing their craft and must be robust enough to handle the different ways in which different practitioners perform their craft.

We experimented with different technologies that could potentially be used for capturing craft gestures. We first used the vision-based technology LeapMotion [13]. The LeapMotion is a device that can track the positions of hands, fingers and tools in 3D space. Using vision-based sensors, it scans for finger-like objects and, when they are found, maps them to a model of a hand. This allows it to make assumptions as to where occluded fingers and tools are in 3D space. However, through our testing, we found that the crochet material (wool) would confuse the device and tool occlusion was a big problem when we performed crochet gestures.

Due to the many different ways in which practitioners may use the material and the tool, we decided that a vision-based technology was not robust enough for our purposes. Next, we considered a wireless inertial measurement unit called WAX [1] – a small (35.8 x 24.5 x 9.1 mm) and light (7.3g) sensor which includes a 3-axis accelerometer, 3-axis gyroscope, 3-axis magnetometer and a Bluetooth radio. The WAX collects data from these sensors and streams them over Bluetooth to any receiver using a binary or CSV format.

Figure 1. Crochet hook with a WAX device attached.

The WAX device has many benefits for our application. The non-reliance on a vision system means that there is no chance of occlusion of the tool, fingers or the material being used. Also, compared to other devices, the fact that the technology is wireless means that it is not tethered to a machine used to create the sonifications and so does not interrupt the practitioner's movements or force them to move in a different way in which they are used to. The small size and weight of the WAX also means that it will not interfere with the normal use of the crochet hook tool.

Choice of Participants

A range of different experiences and proficiency with crochet and craft practice in general was required for our participant group. A group of experts or complete beginners would give us some insight into how sonifications affect the experience of crocheting, but a group with a range of abilities allows us to explore how their differing proficiencies may give rise to different reactions.

We decided to work with an established crochet group who meet regularly in an informal setting to crochet and socialize. They are therefore comfortable discussing and practicing their craft in the presence of others and do so voluntarily as a social occasion and an opportunity for learning. The group was recruited by one of the authors as she has participated in some of the crochet sessions previously. The group has 8 members (5 or more typically attending each meeting), all of whom are female and are aged between 30 and 60 years. Working with this group meant we could be flexible in our workshop format, asking questions to individuals or the whole group as necessary.

Design of the System for Research

We required a system design that would aid us in iteratively designing and testing our sonifications based on our findings between workshops. Therefore we designed the system so it would not only capture the WAX device's data stream and generate sonifications but also save video and audio of each usage. This allows us to alter the design of sonifications in real-time, using real-world data synced with video of the crafter's gestures.

When the data stream is captured, the system also begins recording video of the practitioner's hands via the webcam, the audio produced by the sonification, and the WAX data. At the end of the session, this audio is merged with the video to create a new video file. This allowed us to analyze the sonification generation with respect to the movements the user was performing. It also allowed us to run the data back through the system using different sonifications. This allowed us to design, test and iterate different sonifications using the same real-world data. The system uses a C# application to communicate with the WAX device and to record the video, audio and data files. The data from the WAX device is then processed and the resulting data is streamed to PureData [16], which generates the audio and allows for real-time editing of the sonifications.

Proposed Workshop Structure

Running craft sonification workshops with multiple participants raised several practical concerns. In structuring the workshops, we decided that participants would use the sonification system consecutively but within the same room. This open and flexible format would allow participants to hear each other's sonifications and discuss their practice as a group, rather than on an individual basis. Due to the iterative nature of the design of our system, we did not know in advance what we would be deploying at each workshop so instead planned that each workshop would engage participants in different ways. This was so we could explore how the technology could facilitate participants from different perspectives of craft practice.

As there would be no findings with which to design sonifications for workshop 1, we designed this workshop as a way for the participants to experience using the sonifications and WAX-augmented crochet hook in an open and flexible manner. Participants would attend their crochet group as normal but they would take it in turns to use our WAX-augmented hook with a set of designed sonifications. Workshop 2 was designed as a personalization workshop, where the participants and researchers would use their reflections from Workshop 1 to help modify sonifications together within the workshop using a simplified software interface created in PureData. Workshop 3 would follow the overall format of workshop 1, but participants would instead be learning hooky matting, allowing us to explore how learning a different but similar craft affected the participants' use of the sonification system.

Workshops 1 and 2 were designed to run for three hours including time for the participants to arrive and depart. Workshop 3 was to take place off-site at a heritage museum offering hooky matting courses and so was designed to run for a longer time of six hours, including time to arrive and depart.

DESIGNING AND DEPLOYING SONIFICATIONS

Our prototyping activity was split into two overlapping activities: designing sonifications based on our observations of and reflections upon their deployment; and subsequent workshops where we explored the use of these sonifications with practitioners. Study findings are presented alongside workshop descriptions to enable the reader to follow how our design work and research inquiry developed according to participants' use and discussion of sonifications.

Initial Design Work

In approaching Workshop 1, we based our designs on our background research, initial experimentation with the technology and early tests of the system with the crocheting researcher (discussed earlier). Our initial design proposal was that, by quantifying the gestural properties involved in crocheting, we could produce a form of 'rating system' that would be used to drive a number of designed sonifications.

Quantifying Gesture

To quantify the gestural properties of crocheting, we first needed to decide which properties were important for efficient crocheting. Based on reflections upon a research team member's personal experiences of crochet we came to the conclusion that a skilled crocheter would perform stitches *smoothly*, and at a constant *rate*. Both of these properties are required for efficient crocheting because we can imagine somebody who can smoothly perform one stitch but then must stop between each stitch or between stitches sporadically. We began to translate the movement data given to us by the WAX device into quantifiable properties using digital signal processing techniques on a sliding window. We decided upon three different techniques to give the input movement a rating.

Firstly, we took the input signals from the accelerometer and gyroscope (50Hz sampling rate) in two data window sizes, a short 20 sample window and a long 100 sample window. We then applied smoothing functions to them. By comparing the smoothed versions of the data to the original, we are able to see how smooth the input movements were. Secondly, we performed Fast-Fourier Transform (FFT) [4] on the smoothed input data (the small sample windows meant this did not introduce any discernible latency) to transform the signal from time domain to frequency domain and observe the distribution of low frequencies and high frequencies in the data. If there were a large percentage of high frequencies, then we could deduce that the movement is somewhat sporadic. Thirdly, we calculated the second order derivative of the smoothed input data. This is used to show us where there is a sudden change in movement. By calculating these properties of the input data, we could infer the smoothness of a crocheter's movements. To calibrate the rating system, we altered the rating system's parameters until our colleague's crocheting received an average to good score. Although we did not know how experienced our colleague was, we decided that if she received a score around the center of the rating, we would have a wide enough range for the participants to explore.

Designing Sonifications

We designed three sonifications using very different approaches to support our open-ended and flexible enquiry. This was so that we would be able to collect a range of opinions on the different designs and aesthetics of sonifications. The first design was a simple sonification that would 'beep' if the user's rating dropped below a threshold. We will refer to this sonification as *coaching*. The second sonification was based on natural aesthetics and would play different sounds based on the user's rating in a range. The user would hear the sound of wind that became more aggressive if the rating was low, or calm if the rating was high. If the user was performing particularly well, they would hear birdsong over the calm wind but if they were performing particularly poorly, they would hear thunder and rain. We will refer to this sonification as *wind*. Thirdly, we designed a sonification based around musicality and longer-term use. This sonification would play the sounds of instruments in a repeating melody. If the user's rating stayed above a certain threshold for a period of time, another instrument would join the piece. There were three thresholds in total that the user would have to stay above to hear all of the instruments. We will refer to this sonification as *buildup*.

We chose to attach one WAX sensor to the end of a crochet hook to capture the participants' gestures. We considered using more sensors, such as one for each hand, as crocheting is a bimanual craft. However, through initial testing with our crocheting colleague, we were able to

obtain discernible data from the single sensor setup and translate this into distinguishable sonifications and could see a varied range of ratings within our rating system when different smoothness, speed and stitches were performed.

Workshop 1

Workshop 1 was run with five participants from the local crochet group. The participants had a range of skill levels and experience of crocheting. Pseudonyms are given for individual participants. The workshop was structured in three sections. The participants were first told how each sonification 'worked', after which the participants took it in turns to use the WAX augmented crochet hook to experience each of the three designed sonifications, and finally a focus group-style discussion was held.

Throughout the workshop, one researcher asked questions about crochet and craft practice in general to initiate discussions between the participants. The topics discussed were: learning, teaching, materiality, experience and comparison to other crafts. The questions asked fell into two categories. The first set were deliberately general, to act as impetus for discussion rather constrain discussion to a single topic. The second set asked the participants about their thoughts on the sonification system.

During the course of running workshop 1, we found that the rating system did not work entirely as we expected. When Doris (the most-experienced participant) was very quick at stitching, and in her own words "jerky" and "aggressive". The speed at which she was stitching meant that the system translated her movements into an average-to-low score in the data window we analyzed. The rating system worked much better for the other participants because they were naturally slower in their stitching and therefore, the rating system calculated as much.

However, this problem with the quantitative system was interpreted in an interesting way by the participants. The participants had been told how the *wind* sonification worked, but after Doris played mostly wind rather than birdsong, each subsequent participant tried to match Doris' sound. Therefore, when they generated birdsong they thought they were not doing well because to them Doris must have the best rating. Familiar social interactions in the already established group meant participants tried to emulate the member they perceived to be most experienced.

Aesthetically, the majority of participants preferred *buildup* due to its musical quality. As the participants are friends who meet to crochet weekly, the sessions included casual conversation on familiar topics. Only when *buildup* was being used, everybody was quiet to listen to it. One participant described it as meditative and that it felt like it needed to be given respect. *Wind* was not as popular as *buildup* and one participant said that this was because of the natural sounds. The fact it sounded like nature made it feel like she was in the garden and "*wanted to go back inside*".

When asked the participants about their opinions on the designs of the sonifications, four of the five participants preferred *buildup* to the *coaching* sonification. Hannah expressed "*I felt like I was guiding it* [buildup]*, whereas coaching was guiding me*". This remark was met with agreement by most of the other participants, showing us that using the sonification as a reference and allowing the participant to progress at their own pace is preferable to a sonification which requires the participant to follow it. This was further expressed as participants suggested that *coaching* and *wind* could distract them from crocheting.

Post Workshop 1 Design

Observing that participants were trying to match the most-experienced practitioner's sound and the participants' opinions on the aesthetics of the sonifications led us to explore sonification design from a different perspective: designing abstract and ambiguous sonifications from which the participants could derive their own meaning. We used smoothing functions to smooth the accelerometer and gyroscope data coming from the WAX device but then these smoothed signals were what was used to drive the sonifications directly. Due to the way the system is designed, we were able to take the data recordings from Workshop 1 and run this data and the videos recorded through the system again with these new sonifications. By working in this iterative manner, we were able to design a set of simple, *direct* sonifications in which you could hear different properties of the movement. These sonifications are described as the subset of audification. Their advantage lies in allowing the listener to hear repeated phrases in a data set or signal; therefore we believed this would be useful for hearing the repetitive movements of crochet stitching.

These descriptive sonifications were based on the simple concepts of amplitude modulation and frequency modulation. Each data stream could be used to drive amplitude or frequency modulation (or a combination of both) and each resulting signal could be combined with each other. There were eight data streams available: accelerometer x, y and z and average and gyroscope x, y and z and average.

As workshop 2 was intended to be a workshop to explore and personalize sonifications, we developed a new system to support the ability to alter and combine the different descriptive sonifications. The participants had no experience with PureData and therefore, the interface was designed to be as simple to use as PureData allows. The process of capturing and smoothing different data streams (accelerometer and gyroscope) was hidden from the interface. A simple interface was built which only exposed the volume sliders for each data stream for each descriptive sonification, allowing a user to simply use the slider to merge different data streams with the different forms of descriptive sonification.

Workshop 2

Workshop 2 was run with four participants from the crochet group, three of which had attended workshop 1. The workshop was structured around three sections. We began by discussing the new sonifications with the participants and how they worked. Each participant then used the new sonifications and we finished with a focus group-style discussion. One of the researchers asked questions throughout the session to prompt discussion of their experiences of using the new sonifications and comparisons with the sonifications in workshop 1.

Figure 2. Participant using WAX augmented crochet tool.

Doris and Rachel described how they could hear the difference in the stitches being made when the other participants were using the sonification system. Doris said that she could "see the stitch" in her mind's eye. When it was Margaret's turn to use the system, the other participants could not hear the stitches as well as they could when using it themselves. This began a discussion into the differences in Margaret's crocheting technique as the participants tried to understand why it sounded different. The participants discussed how Margaret must have been manipulating the material with her non-hook hand more than the others did. After this discussion, Margaret expressed "*I didn't know we did things so differently*" even though they had been crocheting together for a long time in these crochet sessions.

After this long discussion about differences in technique, Margaret and Shelley continued to compare techniques. Through demonstrating what she heard in the sonification, Margaret taught Shelley her technique. When asked about this during the focus group-style discussion, Shelley said that she has now realized that she is very "uneconomic" in the way that she crochets and that Margaret's technique is much better. Shelley said she was going to attempt to alter her technique to match that of Margaret's. Here we can see that from a direct result of experiencing the sonifications in a group, a discussion led to participants reflecting on their techniques and one participant teaching the other a technique that she had never tried before.

Aesthetically, Rachel described the amplitude modulation sonification as relaxing, while the frequency modulation sonification was energetic. Shelley discussed how it felt like "*a mental reward*" when you could hear you'd done a stitch smoothly, Rachel echoed this by saying that it was nice to be able to make the sound of a stitch and then repeat making it.

One of the main discussion points during the workshop was about learning techniques. One participant described how she used tutorial videos posted on websites such as YouTube while the others learnt through older family members and used diagrammatic crochet books. We then discussed whether hearing a sonification alongside video could be useful for learning which the participants were positive about.

After discussing if they could hear the stitches when another participant was using the system, Doris and Rachel realized they could not only recognize the stitches but them were following the stitches and rhythm of the sonifications when they weren't creating them. This led them to stop crocheting because they were altering their own crochet projects by accident. This prompted a discussion on whether it would be possible to learn a pattern through sound rather than traditional methods (from a crochet pattern book or with an instructor in person).

Post Workshop 2 Design

Given the positive results of the direct sonifications for generating discussion and aiding reflection and technique modification in workshop 2, we decided to use them again for workshop 3. We also designed two exercises based on discussions of potential applications for the sonifications. Firstly, to create our 'stitch-a-long' exercise, our colleague performed a simple crochet pattern with a variety of stitches using the system to generate a crochet 'sound pattern'. We created a number of these 'sound patterns' of differing complexity to play to the participants in workshop 3. Secondly, to create our sonification video, we video recorded our colleague practicing crochet in the style of a YouTube tutorial. She performed a simple pattern using the WAX augmented hook which we filmed from an over-the-shoulder perspective and then overlaid the sonification audio onto the video.

Workshop 3

Workshop 3 was run with four participants from the crochet group, three of whom had attended workshops 1 and 2. The workshop was structured around three sections. We began by discussing workshop 2 and attempting the exercises we developed. The participants were then taught how to hooky by an instructor from a local living history museum, and we finished with a discussion about the workshop activities. During instruction each participant used a WAX augmented hooky tool so we could explore whether the sonification was useful for learning this new craft. During the course of the workshop, a researcher prompted discussions of their

experiences of learning hooky matting, as well as the differences and similarities with crocheting.

During the stitch-a-long exercise, the participants listened to the different 'sound patterns' and attempted to discern the different stitches. The more experienced crocheters (Doris and Rachel) were able to hear the differences in the stitches, whereas the less experienced crocheters (Shelley and Margaret) could only hear the rhythm.

When using the YouTube mock-up, each participant attempted to stitch along while watching/listening to it. Ann expressed how she found the sound useful to get into a rhythm and would only glance at the video to see where she was and then continue to use the sound to crochet along to. So she described the sound as another support mechanism.

We then moved on to using the direct sonifications for hooky matting. When practicing their hooky matting, the participants expressed that the sonification helped. Most of the participants expressed that they were using it to try to keep to a rhythm. However, Shelley described how she was not using it to stay in rhythm but was using it to hear when she was doing it incorrectly, this is because her sudden movements would cause a loud peak in the sound. Here we see how different participants made use of the ambiguous sound, some using it as positive reinforcement whereas another using it for discerning errors.

During Doris' turn with the sonifications, she expressed that she thought they were helpful to her. We muted the sound from the speakers to test this at which point Doris stopped hooky matting but could not say why at first. She expressed that she felt like there was something missing and that she was following the sound, when the sound was muted she could no longer follow it.

Again, the participants talked about the aesthetics of the sonifications and created their own personal meaning from them. Ann described the sonifications as sounding like an orchestra tuning up and then falling into a rhythm. When you are in a rhythm it is soothing and meditative, when you are not in a rhythm it is exciting to hear the "tuning up" and anticipating the rhythm. She continued by describing the in-rhythm experience as being "in the zone".

The meditative effects of the sound were also discussed throughout the workshop. While using the YouTube mock-up, Doris expressed how she "*felt hypnotized*" and Ann said she felt like she was "*going into a trance*". When using the sonifications for hooky matting, Margaret expressed that the sound was meditative because it was connected directly to your movements, it was not connected consciously.

Summary of Findings

We found that the sonifications affected participants' practice in several ways: participants attempted to *echo the expert* of the group, manipulating their practice to match her sound; when listening to each other's generated sounds, they were able to *perceive differences* between stitches, rhythms and techniques; participants used sonifications as a *resource for the development of practice*, e.g. when Margaret taught Shelley her technique; participants *engaged through sonifications*, describing their aesthetic and meditative effects throughout the workshops; and perceiving stitches in each other's sound led to an *entanglement with practice* as participants altered their own projects unknowingly.

DISCUSSION

In our workshops we observed that sonifications *can* facilitate craft practitioners in discussing, reflecting upon and continuing to learn from their own and each other's practices. Our system for sonifying textile-based craft gestures has demonstrated how sonifications can enable practitioners to explore their own and each other's practice in new ways. Our observations in workshops and collective critical reflections between them suggested several ways in which this happened. Our central finding was that direct sonifications supported reflection and technique modification for the participants whereas preconfigured sonifications did not. We now discuss the ways in which direct sonifications supported the participants' practice.

Enabling Interpretive Flexibility

Through designing different sonifications over the three workshops and observing how participants used them, our findings show that sonifications should be directly linked to the gestural data rather than have meaning imposed upon them by data transformation. The ambiguous sonifications that result are open to interpretation and so allow the participants to derive their own meaning based on what they perceive and interpret in the sounds.

In workshop 1, we designed the sonifications to react in particular ways based on a rating system. We observed that they were not useful to the participants. By designing preconfigured sonifications, we were making assumptions on what the participants would find useful rather than allowing them to make their own meaning. Only *wind* was useful to us from this first set of sonifications, and only in so much as to show us that participants were deriving their own meaning from the sound based on who they want wanted to emulate rather than adhering to the rules which governed the sound produced. This shows us that our prior conceptions of meaning, as expressed in the computational rules were of no use to the participants beyond attempting to emulate the most-experienced crocheter.

The direct sonifications allowed the participants to reflect on their own and each other's practices because they allowed the participants to make their own meanings. In this respect, the sonifications are an example of the reflective design strategy "provide for interpretive flexibility" [20] where users maintain control of and responsibility for the meaning-making process.

Perceiving Differences

The direct sonifications also enabled the participants to perceive differences in their techniques. We found that using the direct sonifications created a situation where one participant's generated sound was not as clear as the other participants', a discussion arose around why this may be. Only through further use of these sonifications did the participants realize that her technique was different from the others and then they were able to discuss these differences. To enable such opportunities for reflection, designers should tailor direct sonifications to better afford personal interpretation and deploy these sonifications to groups rather than individuals to allow the participants' differing interpretations to prompt discussion.

Supporting Reflection Upon and Development of Collective Practice

The ambiguity of the direct sonifications enabled participants to make use of them as they pleased. Given practitioners of varying experience and skill levels, what they hear in the sonifications is different and therefore they interpret what is useful for the development of their practice. Direct sonification of gestures enabled participants to perceive nuances in each other's practices more readily. This supported the group's learning by *doing* through heightening their sensitivities to patterns of gestures associated with differing levels of ability.

We also saw an unexpected consequence of multiple sonifications in group practice. When one participant was using the direct sonifications, a second participant began following the rhythm of the first. Only after some time, did the participant realize that she was doing this and that this was detrimental to her own crochet project. When this happened, this subconscious entrainment was seen as strange and detrimental but this phenomenon could possibly be further explored and used to facilitate the learning of a rhythmic, repetitive craft using direct sonifications in future work.

Reflections on the Design Process

Over the course of three workshops, we explored how to design sonifications with a group of craft practitioners. The design of the system played a vital role in allowing us to explore these sonifications. The ability to record video of the participants and pair these with the recorded gestural data allowed us to explore different sonification designs without needing the participants present.

The system also allowed us to easily manipulate the sonification designs during workshops, which let us respond to points that the participants were making. For example, during workshop 2 one participant expressed that the sound was droning. We were able to manipulate the sonification and receive more feedback from the participant on this change. Furthermore, the direct sonifications that our participants found useful may not be useful to a group of woodworkers for example. Given the variety of different craft practices and the gestures performed to practice them, developing direct sonifications iteratively *with* craft practitioners (e.g. through workshops) is important in order to develop sonifications that are meaningful within their particular practice. A flexible system for producing such sonifications is essential to this process.

Sonifications as Boundary Objects

Participants each heard different things in the sonifications. For some it was rhythm and for others it was the separate stitches, but the whole group was able to discuss common aspects of their practice with respect to the sonifications. In this manner the direct sonifications can be understood as a form of boundary object [22], being flexible enough that it can be interpreted differently by different communities but robust enough to maintain a common identity across them.

The sonifications also acted as a boundary object between the participants and the researchers. Researchers who do not crochet were able to understand concepts the participants were discussing because the discussions were facilitated by the participants' use of sonifications as a reference point, either describing the sound or verbalizing it to help convey an aspect of the craft.

CONCLUSION

In this paper, we have provided a descriptive account of our design-led approach to iteratively designing sonifications for craft practitioners in response to observations and experiences in running a series of workshops. Through working with a group of craft practitioners of varying skill levels, we were able to iteratively design a set of sonifications and example applications that were useful to their practice. By exploring craft through its performative actions (rather than practitioners' descriptions of their making or a semiotic approach to deconstructing artefacts and tools) we have shown how real-time sonification of gestures can facilitate occasions for reflection and discussion of craft skills.

A limitation of our study is that it only investigates the design of sonifications for a particular group of craft practitioners. Further studies with other crafts and groups of practitioners would develop further understanding on how digital systems can aid practitioners in discussing and reflecting on their craft.

We observed how sonifying practitioners' gestural movements can support reflection in and on practice [19] and help them to modify and develop their techniques. This opens up a possibility for remote and en mass learning: could you access the masters' skill by "hearing" it, at a distance? Further, we have demonstrated how sonification can aid practitioners in developing their craft skills but have not explored how this may then aid the preservation of craft skills (e.g. appending sonifications to current learning tools such as YouTube tutorial videos) or how gesture

sonification might be used by complete beginners (working alone or with an experienced practitioner).

During workshops 2 and 3, some of the participants expressed interest in continuing to use the sonification system after our study, e.g. Doris wondered if we could make the technology into an app so that she could use it at home. This highlights an opportunity for longitudinal study, and we have continued to work with participants albeit using different technology – exploring tangible data translation activities utilizing a participatory digital fabrication approach in order to engage craft practitioners in further reflection on their practice.

These limitations notwithstanding, our study opens a space for the sensitive design of digital systems to support reflection in and on craft practice that the HCI community can explore further.

ACKNOWLEDGMENTS

We thank the crochet group who participated in the study. This work was funded by a UK AHRC KE Hub for the Creative Economy (ref: AH/J005150/1 Creative Exchange).

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